A Suite of Tools for Technology Assessment

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What is Technology?

“Technology is defined as the practical application of knowledge to create the capability to do something entirely new or in an entirely new way. This can be contrasted to scientific research, which encompasses the discovery of new knowledge from which new technology is derived, and engineering which uses technology derived from this knowledge to solve specific technical problems.”

- NASA Technology Plan

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What is Technology?

"**1.a.** The application of science, especially to industrial or commercial objectives*. **b.** The entire body of methods and materials used to achieve such objectives."

- The American Heritage Dictionary

Or in NASA's case ***space***

- Technology development lies within the context of part a. and as such is the subject of the remainder of this presentation.
- Engineering makes use of technology within the

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Why is Technology important?

- NASA's Missions cannot meet their goals and objectives without having to rely on advancements in technology.
- Technology development can best be distinguished from engineering development in that it requires venturing into the realm of unknowns - beyond the ability of individuals to make informed judgements based on their experience, i.e.-

HC SVNT DRACONES *

*The Lenox Globe (ca. 1503-07),

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Why do Technology Assessment?

- **You don’t know what you don’t know!**

- Failure to accurately assess technology requirements contributes significantly to schedule slip and cost overrun.
- Even “heritage” systems can require technology development when they are incorporated into a new architecture with different operational environments.
- Technology development cannot be done to schedule - breakthroughs are rarely performed “on demand”.
- Having a “marching army” in place, the middle of a development program is no place to be relying on “miracles” occurring on schedule!

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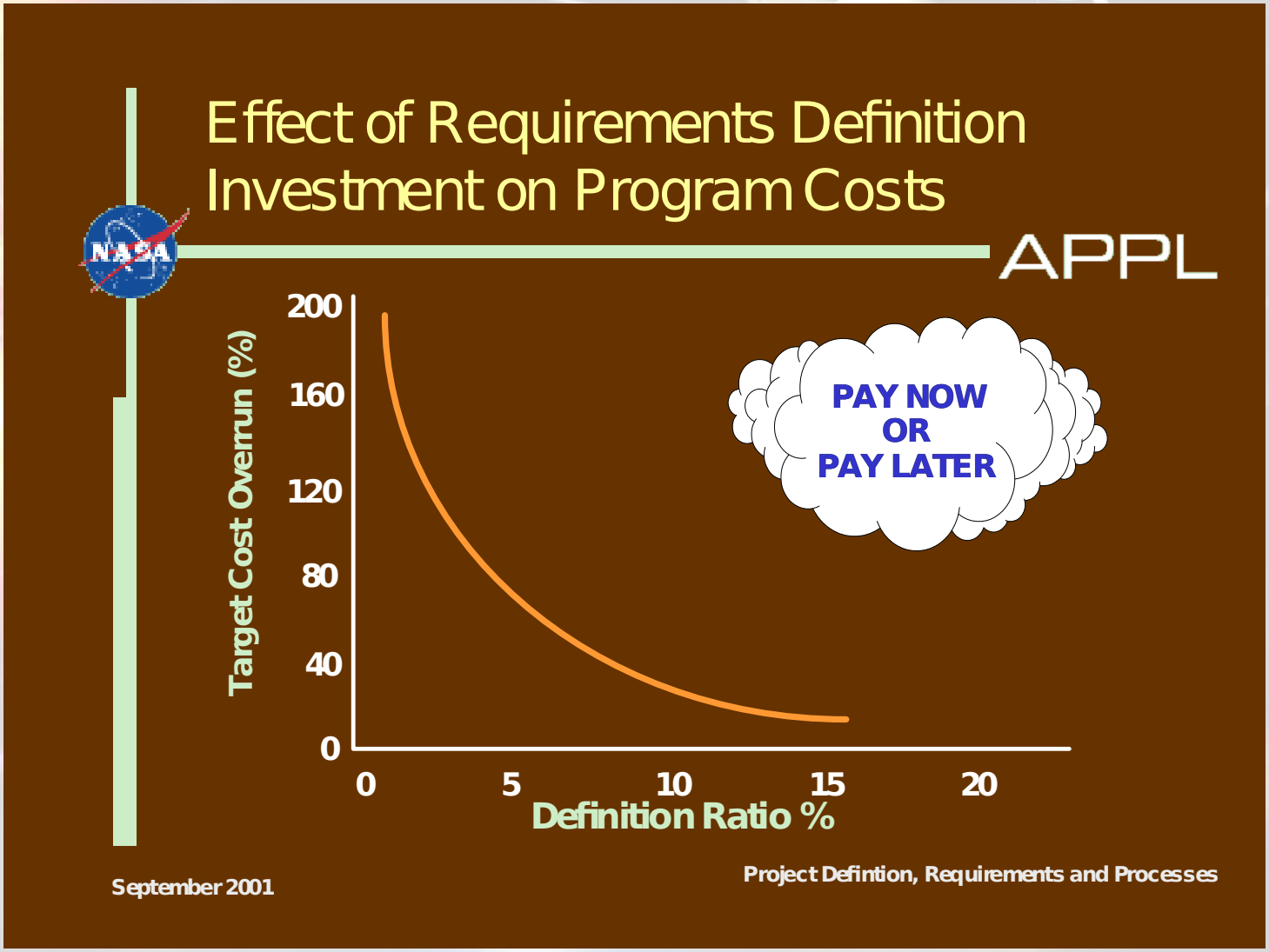

Werner Gruel, 1981/82?

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The Beginning of TRL's

- The idea of ascribing levels of maturity to technology was first documented in a paper "***THE NASA TECHNOLOGY PUSH TOWARDS FUTURE SPACE MISSION SYSTEMS***," (Saden, Povinelli & Rosen, 1989).
- This was a significant change in emphasis on the part of NASA, where technology had previously viewed as merely having a supporting role.
- The change in role was the result of a revision in the National Space Policy stating that NASA's technology program "--*shares the mantle of responsibility for shaping the Agency's future--.*"

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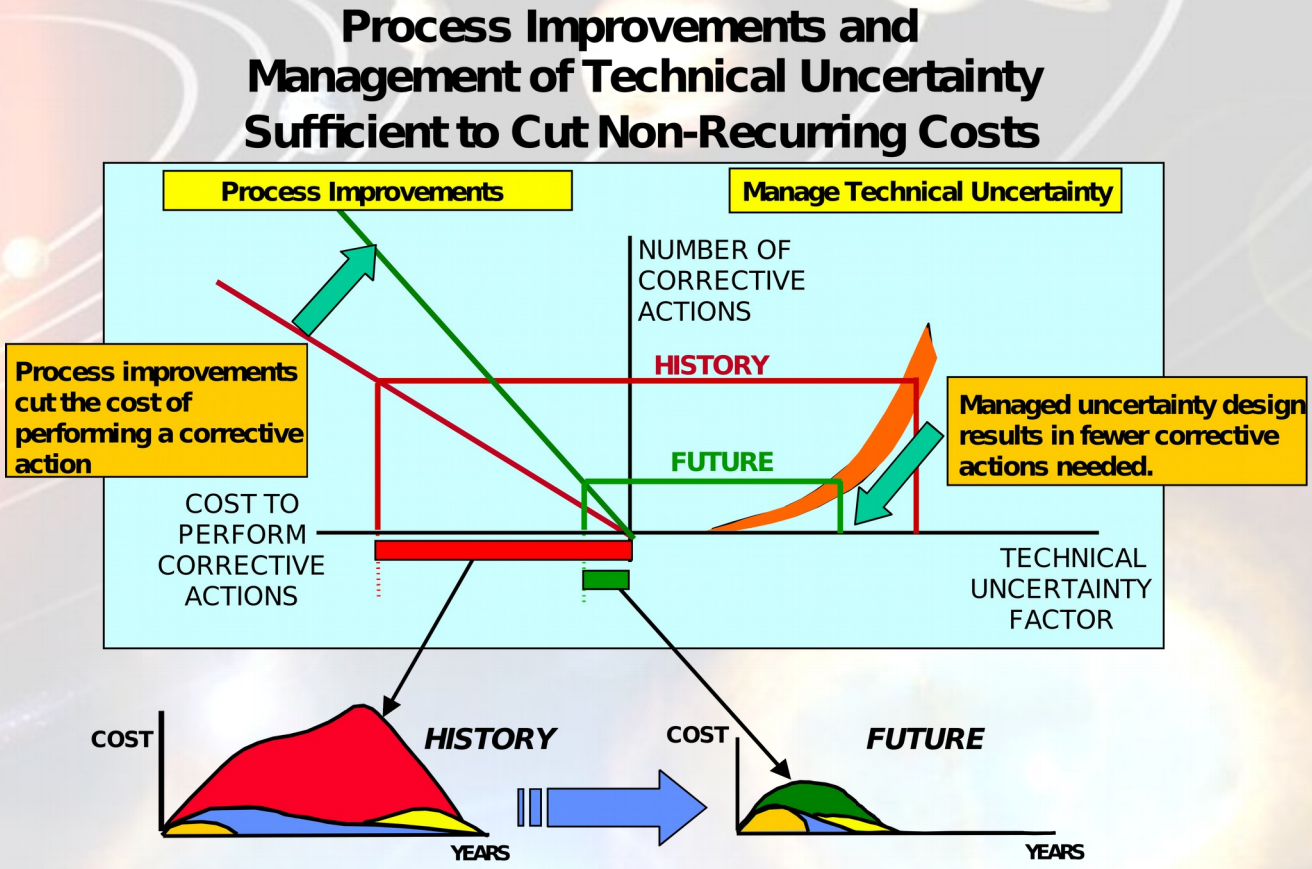

Pratt-Whitney Rocketdyne

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Lessons Learned- Hubble

Major Problems

- Critical lack of knowledge of the state-of-the-art technology in mirror fabrication.
- Computer controlled polishing technology employed by the vendor was immature.
- “Not invented here syndrome” by the vendor resulted in spherical aberration being ground into the mirror.
- Lack of in-depth technical insight by

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Lessons Learned- Chandra

Good	Bad
•NAR identified the issue of scale up - the 0.4 scale technology demonstration mirrors were of insufficient size to address the problems associated with manufacturing the largest of the Chandra mirrors	•Insufficient funding results in the pathfinder program being scaled back, deleting those parts of the program dealing with mirror mounting. •Scale up issues associated with mirror

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Lessons Learned- X-33

- Technology necessary to enable a single-stage-to-orbit did not exist yet program was implemented anyway.

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Lessons Learned- SLI

- Technology necessary to meet performance requirements did not exist.
- Technology program was implemented to develop the necessary technology but –
- The time schedule allotted to the technology development effort was insufficient to permit anything but current technology to be used – which couldn’t meet performance requirements!

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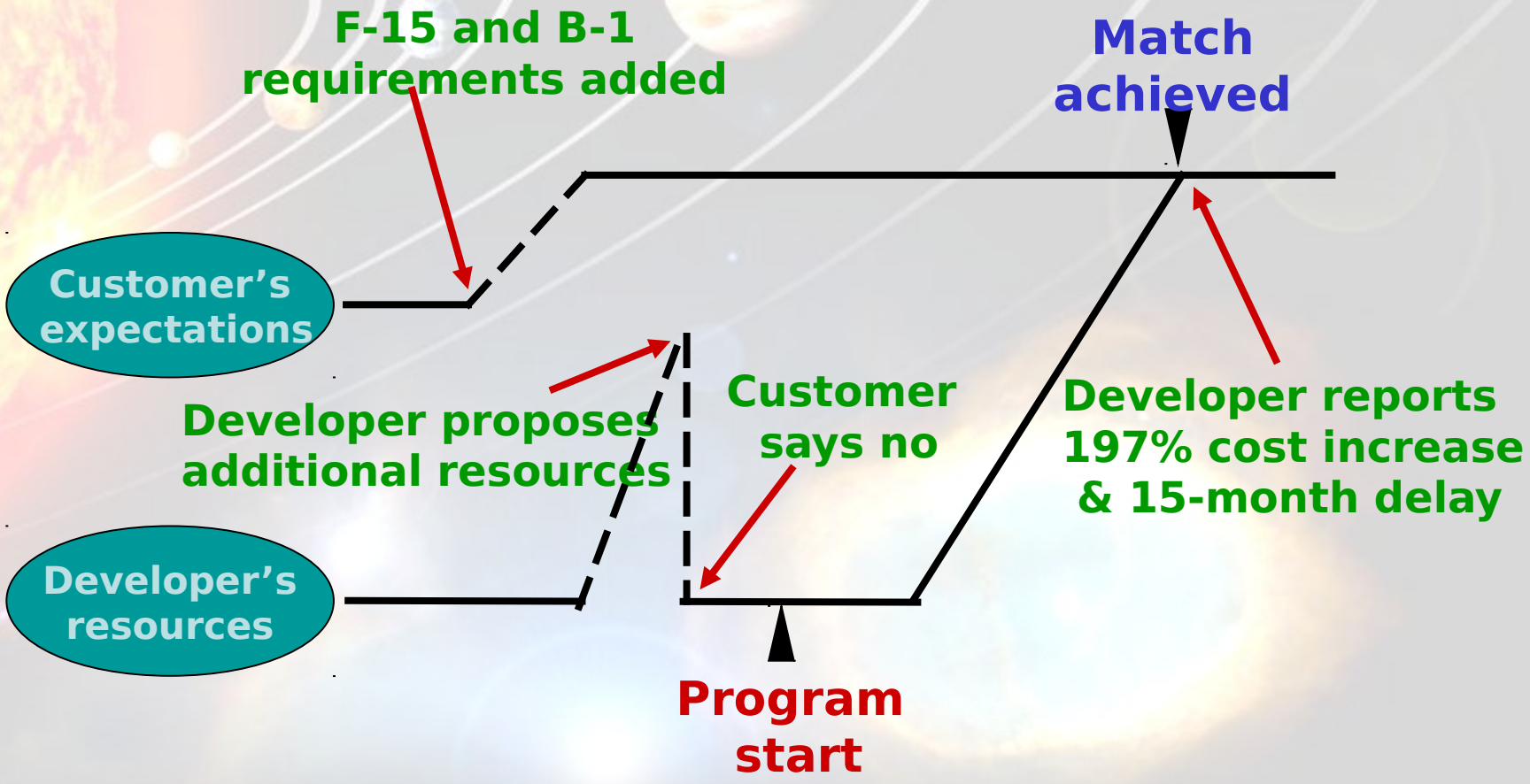
GAO Studies

Development of the Radio Frequency Countermeasures System



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What does Technology Impact?

- Stakeholder Expectation: GAO studies have consistently identified the “mismatch” between stakeholder expectation and developer resources (specifically the resources required to develop the technology necessary to meet program/project requirements) as a major driver in schedule slip and cost overrun.
- Requirements Definition: If requirements are defined without fully understanding the resources required to accomplish needed technology developments then the program/project is at risk. Technology assessment must be done iteratively until requirements and available resources are aligned within an acceptable risk posture.
- Design Solution: As in the case of requirements development, the design solution must iterate with the technology assessment process to ensure that performance requirements can be met with a design that can be implemented within the cost, schedule and risk constraints.

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What does Technology Impact?

- Risk Management: In many respects, technology assessment can be considered a subset of risk management and as such should be a primary component of the risk assessment.
- Technical Assessment: Technology assessment is also a subset of technical assessment and implementing the assessment process provides a substantial contribution to overall technical assessment.
- Trade Studies: Technology assessment is a vital part of determining the overall outcome of Trade Studies, particularly with decisions regarding the use of heritage equipment.

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What does Technology Impact?

- Verification/Validation: The verification/validation process needs to incorporate the requirements for technology maturity assessment in that in the end maturity is demonstrated only through test and/or operation in the appropriate environment.
- Lessons Learned: Part of the reason for the lack of understanding of the impact of technology on programs/projects is that we have not systematically undertaken the processes to understand impacts.

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So – How do you do Technology Assessment?

- It is a two-step process that involves:
  - The determination of the **Technology Readiness Levels (TRLs)** (i.e. current level of maturity) of all of the systems, subsystems and components required to meet program/project requirements.
  - The determination of the **Advancement Degree of Difficulty (AD^2)** (i.e., what is required to advance the immature technologies from their current TRL to a level that permits infusion into the program/project within cost, schedule and risk constraints.

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What is a TRL?

- A Technology Readiness Level (TRL), describes the maturity of a given technology relative to its development cycle.

- At its most basic, it is defined at a given point in time by what has been done and under what conditions.

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TRL Descriptions

Technology Readiness Level - (TRL)	Definition	Hardware Description	Software Description	Exit Criteria
1	Basic principles observed and reported	Scientific knowledge generated underpinning hardware technology concepts/applications.	Scientific knowledge generated underpinning basic properties of software architecture and mathematical formulation.	Peer reviewed publication of research underlying the proposed concept/application
2	Technology concept or application formulated	Invention begins, practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture.	Practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture. Basic properties of algorithms, representations & concepts defined. Basic principles coded. Experiments performed with synthetic data.	Documented description of the application/concept that addresses feasibility and benefit
3	Analytical and/or experimental critical function or characteristic proof-of-concept	Analytical studies place the technology in an appropriate context and laboratory demonstrations, modeling and simulation validate analytical prediction.	Development of limited functionality to validate critical properties and predictions using non-integrated software components	Documented analytical/experimental results validating predicitions of key parameters

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TRL Descriptions - continued

4	Component or breadboard validation in laboratory	A low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments and associated performance predicitions are defined relative to the final operating environment.	Key, functionally critical, software components are integrated, and functionally validated, to establish interoperability and begin architecture development. Relevant Environments defined and performance in this environment predicted.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of relevant environment.
5	Component or breadboard validation in a relevant environment	A mid-level fidelity system/component brassboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrates overall performance in critical areas. Performance predictions are made for subsequent development phases.	End-to-end Software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system, tested in relevant environment, meeting predicted performance. Operational Environment Performance Predicted. Prototype implementations developed.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements
6	System/subsystem model or prototype demonstration in a relevant environment	A high-fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.	Prototype implementations of the software demonstrated on full-scale realistic problems. Partially integrate with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.	Documented test performance demonstrating agreement with analytical predictions

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TRL Descriptions - continued

7	System prototype demonstration in space	A high fidelity engineering unit that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate performance in the actual operational environment and platform (ground, airborne or space).	Prototype software exists having all key functionality available for demonstration and test. Well integrated with operational hardware/software systems demonstrating operational feasibility. Most software bugs removed. Limited documentation available.	Documented test performance demonstrating agreement with analytical predictions
8	Actual system completed and flight qualified through test and demonstration	The final product in its final configuration is successfully demonstrated through test and analysis for its intended operational environment and platform (ground, airborne or space).	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation completed. All functionality successfully demonstrated in simulated operational scenarios. V&V completed..	Documented test performance verifying analytical predictions
9	Actual system flight proven through successful mission operations	The final product is successfully operated in an actual mission.	All software has been thoroughly debugged and fully integrated with all operational hardware/software systems. All documentation has been completed. Sustaining software engineering support is in place. System has been successfully operated in the operational environment.	Documented mission operational results

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What is AD^2?

- The TRL is just one part of the equation – and the initial assessment establishes the baseline for the program/project.

- The more fundamental question is what is required (in terms of cost, schedule and risk to move the technology from where it is to where it needs to be.

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What is an Advancement Degree of Difficulty (AD^2)?

- **AD2** is a method of dealing with the other aspects beyond TRL, it is the description of what is required to move a system, subsystem or component from one TRL to another.
- It takes into account:
  - Design Readiness Level
  - Manufacturing Readiness Level (MRL)
  - Integration Readiness Level (IRL)
  - Software Readiness Level (SRL)
  - Operational Readiness Level
  - Human Readiness Levels (HRL) (skills)
  - Capability Readiness Levels (CRL) (people and tools)
  - organizational aspects (ability of an organization to reproduce existing technology)
  - Etc.

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What is an Advancement Degree of Difficulty (AD^2)?

Degree of Difficulty	Description
9	100% Development Risk - Requires new development outside of any existing experience base. No viable approaches exist that can be pursued with any degree of confidence. Basic research in key areas needed before feasible approaches can be defined.
8	80% Development Risk - Requires new development where similarity to existing experience base can be defined only in the broadest sense. Multiple development routes must be pursued.
7	60% Development Risk - Requires new development but similarity to existing experience is sufficient to warrant comparison in only a subset of critical areas. Multiple development routes must be pursued
6	50% Development Risk - Requires new development but similarity to existing experience is sufficient to warrant comparison in only a subset of critical areas. Dual development approaches should be pursued in order to achieve a moderate degree of confidence for success. (Desired performance can be achieved in subsequent block upgrades with high degree of confidence.)
5	40% Development Risk - Requires new development but similarity to existing experience is sufficient to warrant comparison in all critical areas. Dual development approaches should be pursued to provide a high degree of confidence for success.
4	30% Development Risk - Requires new development but similarity to existing experience is sufficient to warrant comparison across the board. A single development approach can be taken with a high degree of confidence for success.
3	20% Development Risk - Requires new development well within the experience base. A single development approach is adequate.
2	10% Development Risk - Exists but requires major modifications. A single development approach is adequate.
1	0% Development Risk - Exists with no or only minor modifications being required. A single development approach is adequate.

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When do you do a Technology Assessment (TA)?

- It is extremely important that a Technology Assessment process be defined at the beginning of the program/project.
- It is also extremely important that it be performed at the earliest possible stage (concept development) and repeated periodically throughout the program/project through PDR.
- Inputs to the process will vary in level of detail according to the phase of the program/project in which it is conducted.
- Even though there is a lack of detail in pre-phase A, the TA will drive out the major critical technological advancements required.

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Example Pre Phase A Product: James Webb Telescope

Optical Telescope Assembly
- **Ultralightweight Mirrors**
- **Cryogenic Actuators**
- **Cryogenic Deformable Mirror**
- Deployable Structures
- Wavefront Sensing & Optical Control

Science Instrument Module
- **Low Noise NIR Detectors**
- High Q.E. TIR detectors
- Large Format Arrays
- Digital mirror
- Vibrationless Cryo-Coolers

Mission Operations
- **Flight Software Methodologies**
- **Autonomous On-board Schedule Execution**
- Data Compression
- Control Executive
- Autonomous Fault Management
- User Interaction Tools

Spacecraft Support Module
- **Inflatable or Deployable Sunshade**
- **Vibration Isolation**
- Advanced Startracker
- Low Temperature Materials Property Characterization

Systems
- **Integrated Modeling**
- **Mission Simulator**

“TALL TENT POLES” IN BOLD

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How often do you do a Technology Assessment (TA)

As defined by NPR 7120.5d,
NASA Space Flight Program and Project Management Requirements

- **KDP A – Transition from Pre-Phase A to Phase A:**
  Requires an assessment of potential technology needs versus current and planned technology readiness levels, as well as potential opportunities to use commercial, academic, and other government agency sources of technology. Included as part of the draft integrated baseline.

- **KDP B – Transition from Phase A to Phase B:**
  Requires a Technology Development plan identifying technologies to be developed, heritage systems to be modified, alternate paths to be pursued, fall back positions and corresponding performance de-scopes, milestones, metrics and key decision points. Incorporated in the preliminary Project Plan.

- **KDP C – Transition from Phase B to Phase C/D:**
  Technology Readiness Assessment Report (TRAR) demonstrating that all systems, subsystems and components have achieved a level of technological maturity with demonstrated evidence of qualification in a relevant environment.

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How do you start?

Define Your Terms!

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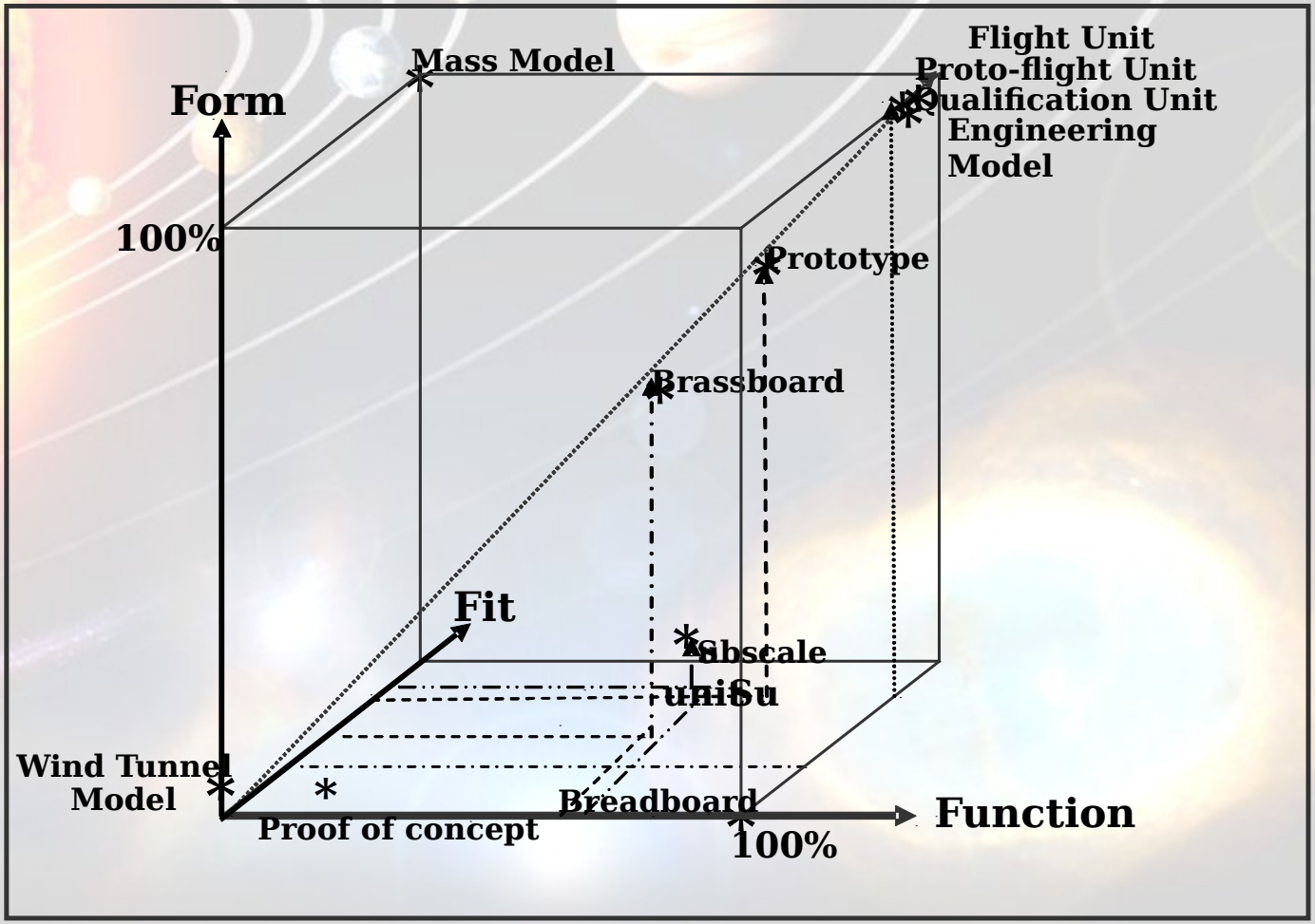
Form Fit & Function Definitions



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Definitions

- **Proof of Concept: (TRL 3)**
  Analytical and experimental demonstration of hardware/software concepts that may or may not be incorporated into subsequent development and/or operational units.

- **Breadboard: (TRL 4)**
  A low fidelity unit that demonstrates function only, without respect to form or fit in the case of hardware, or platform in the case of software. It often uses commercial and/or ad hoc components and is not intended to provide definitive information regarding operational performance.

- **Developmental Model/ Developmental Test Model: (TRL 4)**
  Any of a series of units built to evaluate various aspects of form, fit, function or any combination thereof. In general these units may have some high fidelity aspects but overall will be in the breadboard category.

- **Brassboard**: **(TRL 5 – TRL6)**
  A mid-fidelity functional unit that typically tries to make use of as much operational hardware/software as possible and begins to address scaling issues associated with the operational system. It does not have the engineering pedigree in all aspects, but is structured to be able to operate in simulated operational environments in order to assess performance of critical functions.

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Definitions - continued

- **Laboratory Environment:**

  An environment that does not address in any manner the environment to be encountered by the system, subsystem or component (hardware or software) during its intended operation. Tests in a laboratory environment are solely for the purpose of demonstrating the underlying principles of technical performance (functions) without respect to the impact of environment.

- **Relevant Environment**:

  Not all systems, subsystems and/or components need to be operated in the operational environment in order to satisfactorily address performance margin requirements. Consequently, the relevant environment is the specific subset of the operational environment that is required to demonstrate critical “at risk” aspects of the final product performance in an operational environment.

- **Operational Environment:**

  The environment in which the final product will be operated. In the case of spaceflight hardware/software it is space. In the case of ground based or airborne systems that are not directed toward space flight it will be the environments defined by the scope of operations. For software, the environment will be defined by the operational platform and software operating system.

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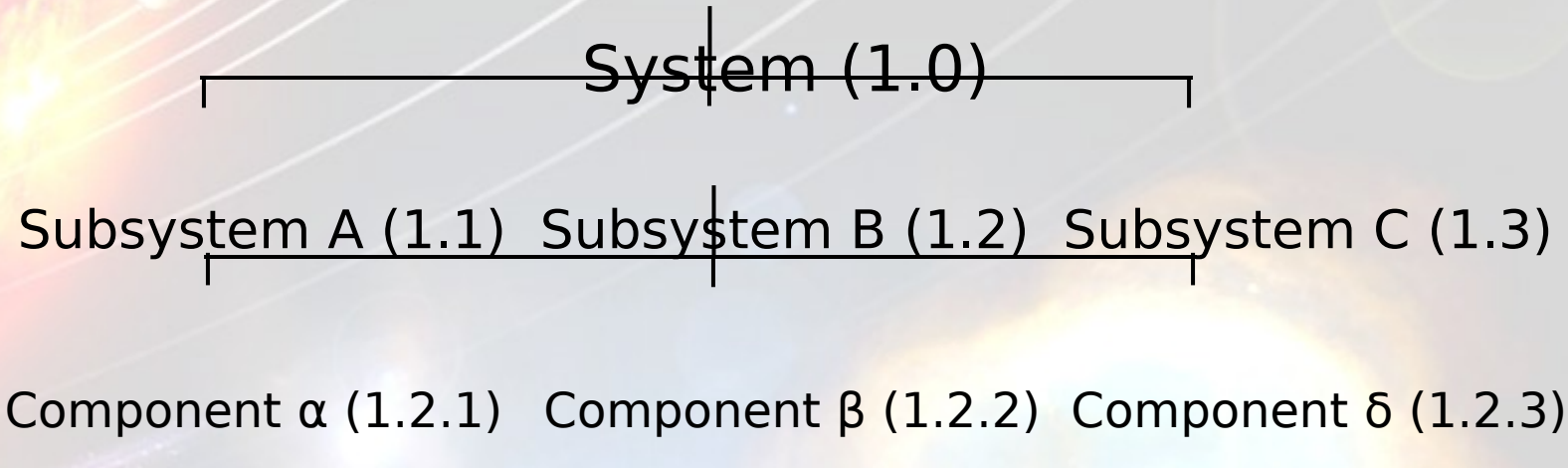
Develop a Work Breakdown Structure (WBS)



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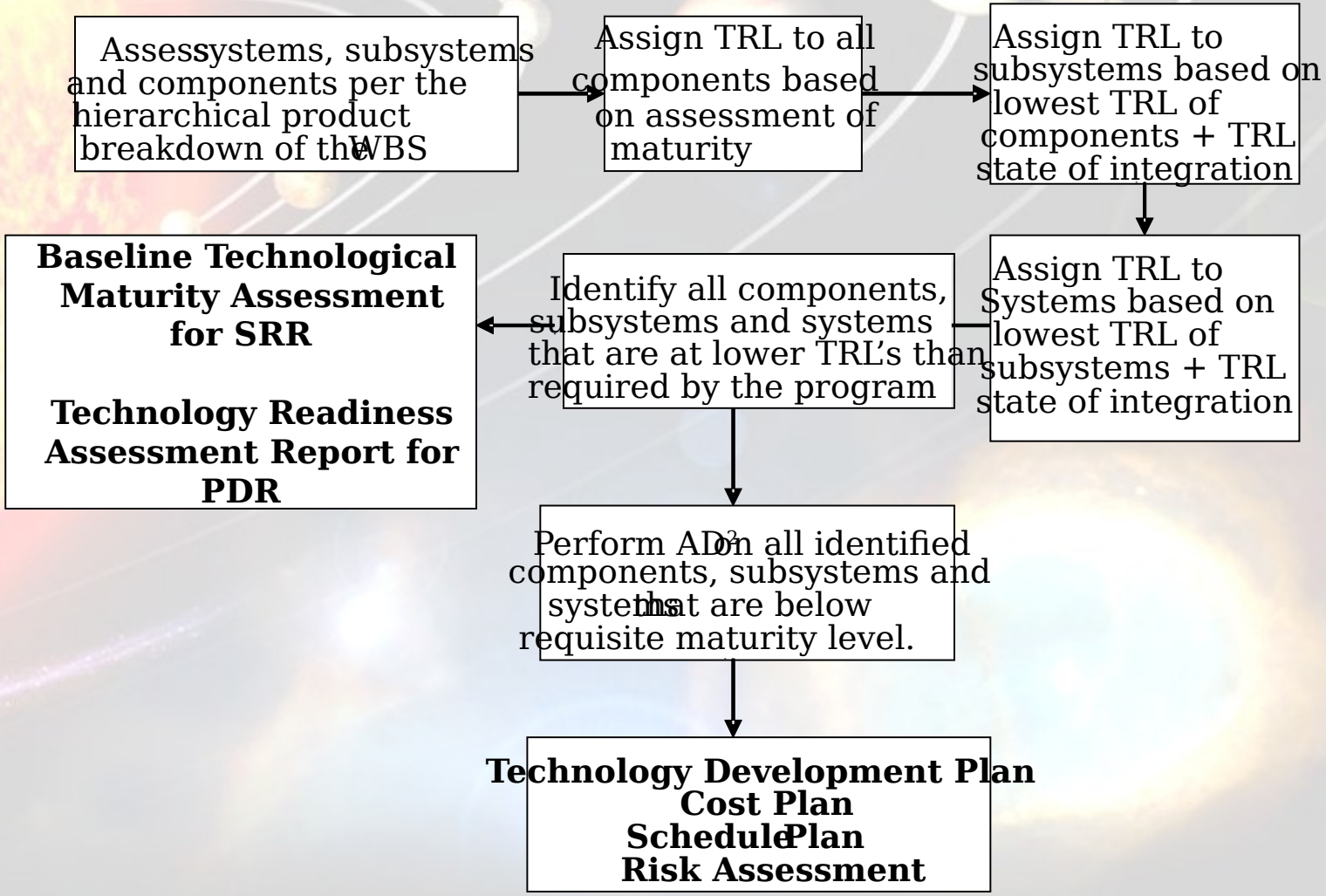
Start the Process


Assess systems, subsystems and components per the hierarchical product breakdown of the WBS
Assign TRL to all components based on assessment of maturity
Assign TRL to subsystems based on lowest TRL of components + TRL state of integration
Assign TRL to Systems based on lowest TRL of subsystems + TRL state of integration
Identify all components, subsystems and systems that are at lower TRL's than required by the program
Perform AD2 on all identified components, subsystems and systems that are below requisite maturity level.
Baseline Technological Maturity Assessment for SRR
Technology Readiness Assessment Report for PDR
Technology Development Plan
Cost Plan
Schedule Plan
Risk Assessment

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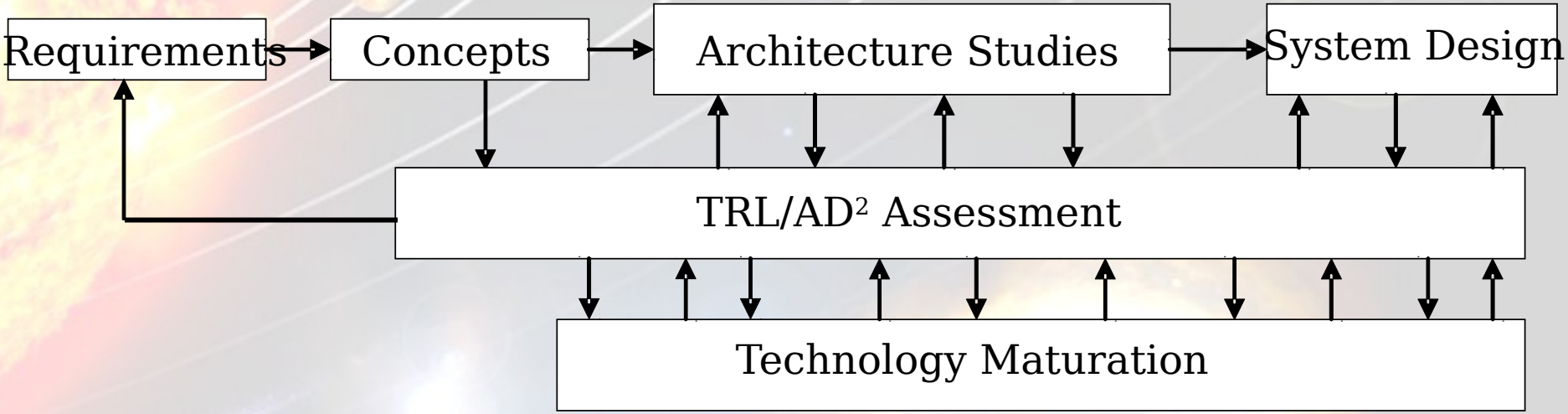

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Helpful Tools

- **TRL Calculator**
- **AD2 Calculator**

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Summary

- **The TRL assessment provides the baseline maturity at the start of a program/project and is the basis for the preparation of the Technology Readiness Assessment Report required for delivery at PDR.**
- **The AD2 assessment provides the basis for the development of the Technology Development Plan and for improved accuracy of the development of program/project cost, schedule and risk.**
- **Technology Assessment is vital to program/project success!**

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